A Technical Overview of the EVN

Pablo de Vicente

Abstract In this paper we present an overview of the European VLBI Network (EVN) from the technical side. We descibe the frequency bands used, the equipment at the stations, the different types of observations, and how they are organized. There is also a description of the latest technical developments, whose main goal is to achieve two polarizations 512-MHz wide with a recording rate of 4 Gbps. All these tasks lie within the role of the Technical and Operations Group (TOG) of the EVN that is also in charge of maintaining the quality of the results of the network.

Keywords VLBI, EVN

1 Introduction

The European VLBI Network (EVN) is a collaboration of the 14 major radioastronomical institutes in Europe (including the Joint Institute for VLBI ERIC), Africa, and Asia, whose main goal is to perform astronomical high angular observations of cosmic sources. This is achieved using Very Long Baseline Interferometry (VLBI) among telescopes at the different observatories of the institute members. The EVN operates 21 telescopes and two correlators.

The EVN has a governing body formed by the Consortium Board of Directors (CBD), a Technical and Operations Group (TOG), and a Programme Committee (PC). The chairs of the two latter groups report to the CBD every six months.

Observatorio de Yebes, Instituto Gegráfico Nacional

2 The TOG

The Technical and Operations Group dates back to 1982 (by that time it started being called the TWG), although minutes from past meetings are public available only since 1992. The TOG is in charge of the operations and technical developments of the network. It is composed of VLBI friends at the stations and personnel at the correlators. The TOG meets periodically approximately every nine months, rotating the location through the different observatories. The meetings are open and are also regularly attended by non-EVN members, like the FS main developer or staff from Haystack and NRAO. The meetings are organized so that they do not coincide with EVN sessions. Once every three meetings the TOG chair tries to match it with the EVN symposium and EVN users' meeting, looking for a direct interaction between the technical personnel and the users. Beginning in 2016, the TOG will meet together with the Global Millimeter Array (GMVA) Technical Group every other meeting. The goal is to exploit synergies, look for common developments, and benefit from the exchange of information between both communities.

The TOG resources are distributed among different EVN partners who host different servers. The main TOG Web page is currently hosted at http://www.oan.es/evn/tog.html and it acts as starting point to access all the resources. This page is also reachable from the main EVN Web page: http://www.evlbi.org. The sources of information are the TOG wiki, hosted by MPIfR in Bonn: https://deki.mpifr-bonn.mpg.de/Working_Groups/EVN_TOG.html and the Radionet3 wiki Web page: http://www.radionet-eu.org/radionet3wiki/doku.php?id=na:eratec:tog. The first wiki contains information about disk status, disk purchases, spares, last and permanent action items, and technical information, including scripts, procedures, and descriptions to perform tasks at the stations. The second wiki is basically devoted to TOG meetings. It archives the agenda, minutes, reports, and talks from past meetings. The JIVE Web page and servers maintain all information regarding feed back from observations, observed and correlated experiments, and about real time correlation. The schedules and logs are stored in the EVN FTP hosted by the Istituto Nazionale di Astrofisica (INAF) in Italy. The main communication channel is the mailing list hosted by Jodrell Bank and is known as the EVNtech email list.

3 EVN Observations

The EVN observes between 21 cm and 7 mm. There are seven main bands whose frequencies were chosen to make them match with interesting spectral molecular or atomic lines. Table 1 lists the frequencies, bandwidths, and lines on which they are centered. The 21-cm band is centered on the atomic H line, and the 18-cm band is centered on the OH maser line. 13 cm and 3.6 cm are also bands chosen because they are compatible with geodetic S/X observations. Other bands are 6 cm and 5 cm, the latter centered around the CH_3OH maser line. Finally the upper bands are 1.3 cm around the H_2O maser line and 0.7 cm around the SiO maser line. Available instantaneous bandwidths depend on the frequency ranges and vary between stations, the largest being 500 MHz. Many telescopes can tune their local oscillators and the observable bands are larger than 500 MHz, for example several GHz for 22 and 43 GHz at some telescopes. This information is kept in one of the catalogs at JIVE. The most used bands during EVN observation are 5 cm, 6 cm, and 18–21 cm.

Most of the EVN telescopes are equipped with DBBC2 backends built by HAT-Lab in collaboration with MPIfR. The DBBC2s contain four IFs and four COREs and a Fila10G board which can generate VDIF data rates up to 8 Gbps. However, not all telescopes have fully equipped DBBC2s. The Russian KVAZAR telescopes use their own DAS R1002 backend, and the Korean stations also use a Korean Data Aquisition System. Robledo uses a data aquisition unit (DVP) built by JPL. The recorders used are Mark 5A, Mark 5B, Mark 5B+, Mark 5C, Flexbuf, and Mark 6. Updated information on the recorders and the firmware that they use is compiled on the following Web page: http://mark5-info.jive.nl/. Most of the stations record in Mark 5B format, although during 2015 two stations, Ef and On, began recording data in VDIF format.

Table 1 Frequency bands covered by the EVN. Band widths depend on the individual stations.

Band	Bandwidth	Main interest
21 cm	60–500 MHz	H maser
18 cm	60–500 MHz	OH maser
13 cm	300 MHz	S/X geodetic S band
6 cm	500 MHz	Continuum emission
5 cm	425, 500 MHz	6.6 GHz CH_3OH maser
3.6 cm	500 MHz	S/X geodetic X band
1.3 cm	100, 400, >500 MHz	22 GHz H_2O maser
0.7 cm	>500 MHz	43 GHz SiO maser

Standard observations at the EVN consist in observing two bands 128-MHz wide each at right and left circular polarization, which corresponds to a recording rate of 1024 Mbps. This rate is limited by a DBBC2 equipped with two COREs and a Mark 5B recorder if Mark 5B format is used. Higher rates require four COREs in DDC mode and at least a Mark 5B+ recorder. Since EVN 2015-3 the EVN offers two bands 256-MHz wide with a recording rate of 2 Gbps at all stations except two.

The EVN groups observations along the year in three blocks called sessions. Several weeks prior to each session there is a call for proposals which are evaluated by the Program Committee (PC). Proposals rated best are scheduled and observed. Each session is divided into blocks according to the observing frequency. The sessions usually take place in February/March, May/June, and October/November. The scheduler keeps contact with the Global Millimeter Array (GMVA) scheduler and the IVS scheduler to avoid observational conflicts, because some EVN telescopes also belong to the GMVA and IVS networks. The number of observations programmed depends on the available disk space at the stations and correlator. Currently, with a recording rate of 1 Gbps, the typical usage per station and session is 60 TB. The schedules are made by JIVE where a customized catalog and a patched version of SCHED is kept.

Apart from the standard science observations during sessions, the EVN performs other types of observations. Network Monitoring Experiments (NME)

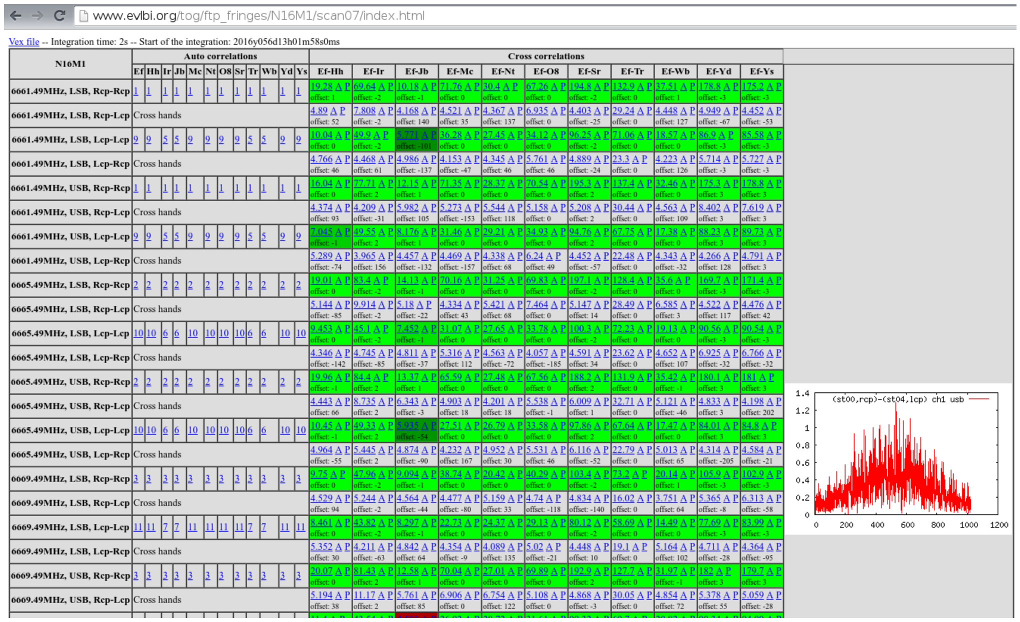

Fig. 1 The Web page evlbi.org showing results from the correlation after transferring a part of a scan to JIVE correlator. Results from all baselines to a single reference station are shown. Amplitude and phase together with autocorrelation are displayed for both polarizations and for cross polarizations.

are observations that preceed a frequency block during an EVN session. The stations transfer slots of selected scans to the correlator where the data is correlated. The goal of these observations is to debug problems some hours before the science observations to be able to tackle them. Fringe tests are another kind of EVN observation and their purpose is to test a development not restricted to the EVN sessions. They can be scheduled at any time and usually are restricted to a subset of telescopes, namely those that are available and willing to implement the new features to test. Both types of observations are correlated in near-real time, and the results displayed on a Web page at JIVE: http://www.evlbi.org/tog/ftp_fringes/. Figure 1 shows an example. There are some cases in which some fringe tests are diskless and the data is tranferred in real time to the correlator.

Out-of-session Observations (OoS) happen six days per year. They require a long-term cadence and time specific requirements and they are usually associated with the Radioastron project. e-VLBI observations are diskless transfers of data to the correlator where they are correlated in real time. Each observation usually takes 30 hours and they are distributed along the year, in several periods. Usually the first hours of the observation are reserved for tests. Target of Opportunity (ToO) observations is another category of observations. Their goal is to react to a transient event. They require a fast review and scheduling and if their rating is high enough they can override a running schedule. For the time being, ToO observations can only happen during an e-VLBI period.

All observations automatically send the LOG to the EVN FTP server hosted in Bologna, Italy, and observers fill a feedback form after the observation has completed. Previous to the EVN sessions, telescopes should reserve time for an amplitude calibration observation that allows to determine the gain of the antenna and noise temperature of the diodes along a frequency band. This is achieved with ONOFF observations. The EVN is trying to extend the usage of continuous calibration driven by a 80-Hz signal to all telescopes. This method reduces the time devoted to calibration and monitors the gain changes through the receiving chain.

4 Technical Developments

One of the short-term technical goals of the EVN is a recording rate of 2 Gbps for e-VLBI and recorded experiments, and 4 Gbps for recorded experiments in the near future. 2 Gbps, which corresponds to two bands of 256 MHz, should be implemented at all stations by 2017 and 4 Gbps (2 bands 512-MHz wide) one year later. To achieve this goal the EVN signed a contract with NVI in 2015 to provide new features in the FS which had to be completed in one year approximately. This agreement was composed of three steps which had to be covered by a FS release each time.

The first goal was to provide support for 32 MHz per channel in DDC mode. FS version 9.11.7 released in April 2015 and the DBBC firmware V105E_1 released by HAT-Lab in January 2015 covered this goal. This mode is available within the EVN since then and it is offered in the call for proposals since fall 2015. This is currently implemented and working.

The second step consisted in providing support for VDIF data and therefore for Fila10G, Mark 5C, Flexbuff, and Mark 6 recorders. This was accomplished by Fila10G firmware version 3.3, FS version 9.11.8, and jive5ab versions above 2.6.0. This has been supported and available since October 2015. Currently, three EVN stations benefit from this deveplopment and within the next months others will follow. This step is closely related to the jive5ab software. jive5ab is a crucial software in the EVN; the TOG agreed in 2014 to replace Dimino by jive5ab at all EVN stations. jivea5ab is a development mainly by Harro Verkouter (JIVE) and it manages the recording of data. It works on Mark 5A, Mark 5B, Mark 5B+, Mark 5C, Mark 6, and Flexbuff. It is supported in 32 and 64 bit OS Linux versions and works for several Debian versions: Etch, Lenny, and Wheezy. jive5ab supports VDIF and Mark 5B format. Together with jive5ab there are some useful tools like m5copy to copy data between the different recorders. This can be used to transfer data between the stations and the correlator at high speeds, up to 800 Mbps. In the Flexbuff and the Mark 6 there is also a virtual file system, based on a fuse that allows to gather the data from an experiment distributed in different disks. For further information see Verkouter in this same volume.

The third step consisted in providing support for the PFB mode. This is the mode that will be required for 4-Gbps operations. Currently, there are several FS beta versions, 9.11.9 to 9.11.13, that address the issues that have arisen. The successive versions have been tested successfully in January, April, and May 2016 (experiments FR028, FR030, FR031, FRO033, and FR034). Support for radiometry is already in place and, at the time of this paper, some tests still need to be performed to check the validity of the last version.

One of the latest technical developments accomplished by the TOG was the adoption of 2-Gbps e-VLBI. This mode has been implemented after extensive tests performed during the last months. The usage of Mark 5Bs imposed a limitation of 1 Gbps in the transfer of data in real time. The correlator connected to the station's Mark 5B or Mark 5C and managed the data flow using jivea5b. However, increasing the data rate to 2 Gbps required that the DBBC2 sent the data directly to the correlator. The DBBC2 generates data in VDIF format that can be sent in a single thread with different frames, one per frequency band, or in different threads, one per frequency; both cases were tested. The single thread multi-frame works with a payload of 8,000 bytes per frame and the multi-thread single-frame one with 2,000 bytes. The former matches the requirements of the correlator. The second one, although it also matches the capability of the correlator, imposes a load on the CPU: smaller frames require more processing. The data flow control from the correlator was achieved by a proxy, a server program that listens to the FS and to a second client (from the correlator), and which forwards commands to the DBBC2 and receives answers which are sent back to the caller. This is the way to control the data flow and start and stop it when required at the correlator. The proxy is installed on a host in the public local area network to prevent malicious access to the FS which controls the radio telescope.

After this development, the EVN has announced in the last call for proposals, in May 2016, the possiblity to perform e-VLBI observations at a rate of 2 Gbps with at least six stations. Once the 4-Gbps recording rate mode is fully tested, this mode will be announced at the EVN and it should also be available for e-VLBI observations, provided the stations have 10 Gbps connection lines to the Internet.

References

1. Harro Verkouter (JIVE — ERIC). "Of Flexing your buffers and Marking your 6's". 4th International VLBI Technology Workshop, 2015.